

CHAPTER 5

Post-Launch Calibration Using On-Board Calibration (OBC) Systems

OBJECTIVE

- Post-launch, the goal in using the on-board calibration systems is to obtain accurate calibration coefficients and characterization information sufficient to calibrate the MODIS data to the levels required by instrument specification.
- The on-board calibrators will be the primary element in the at-launch calibration algorithm. The on-board calibrators also serve as the transfer of preflight calibration to on-orbit.
- The OBCs may not be adequate over time as they and the instrument change. As vicarious and image-derived calibrations become available, these other sources will be integrated with the OBC calibration coefficients both to validate the OBC results and to improve the overall accuracy of the MODIS calibration.

METHODOLOGY

Determine calibration coefficients from:

Space View (SV)	reflective and thermal bands--first data point
Blackbody (BB)	thermal bands--second data point
Solar Diffuser (SD)	reflective bands--second data point (inter-orbit scales)
SRCA Radiometric Mode	reflective bands--second data point (intra-orbit time scales)

Baseline SBRC Plan: Use two points and pre-launch calibration curve to determine calibration coefficients.

Get characterization information from:

SRCA Spectral Mode	Center Wavelength, etc.
SRCA Spatial Mode	Band-to-Band Registration
Solar Diffuser Stability Monitor (SDSM)	SD Degradation
Electronic Calibration	Electronics & A/D Linearity

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

Requirements From Instrument Specification

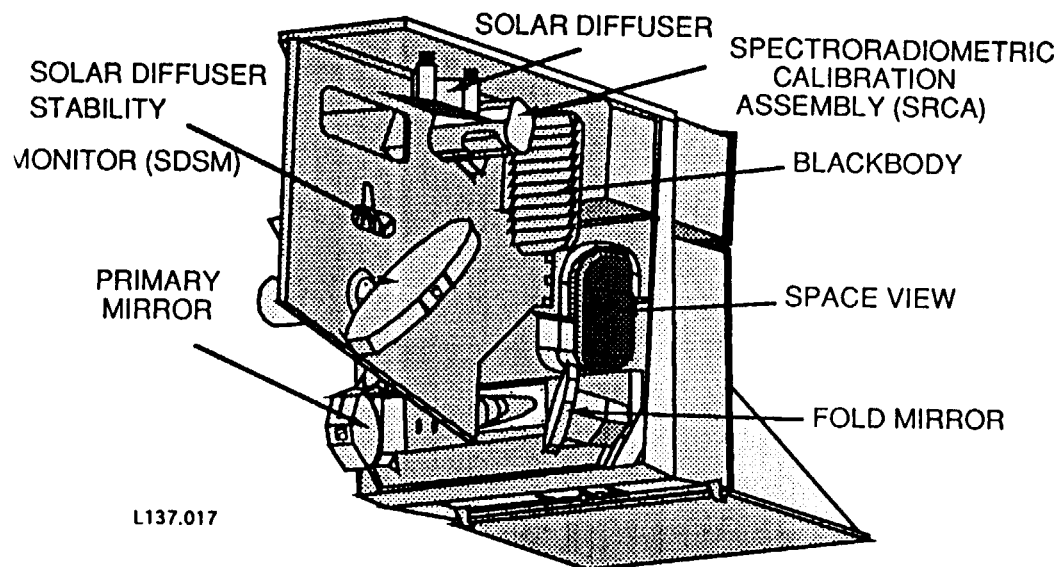
CDR predicted uncertainties for on-board calibrators

Characteristic	Bands	On-board calibrator	Requirement	Prediction
Absolute radiometric accuracy at $L_{typical}$ *	1-19, 26	SD/SDSM, SV	5%	4.4%
Absolute radiometric accuracy at $L_{typical}$ *	21-25, 27-30, 33-36	BB, SV	1%	1%
Absolute radiometric accuracy at $L_{typical}$ *	20	BB, SV	.75%	0.74%
Absolute radiometric accuracy at $L_{typical}$ *	31, 32	BB, SV	.5%	0.5%
Reflectance accuracy at $L_{typical}$ *	1-19, 26	SD/SDSM, SV	2%	2%
Relative radiometric stability	1-19, 26	SRCA	1%	1%
Spectral CW accuracy		SRCA	scales; 1-2.3 nm	scales; 0.6-1.4nm
Spectral CW precision		SRCA	scales; 0.5-1.1 nm	by band; 0.3-0.7nm
Spatial coregistration		SRCA	0.2 IFOV	0.1 IFOV

*At any other radiance level between $0.3 \cdot L_{typical}$ and $0.9 \cdot L_{max}$, the uncertainty can be 1% higher than that at $L_{typical}$

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SPACE VIEW PROVIDES A NOMINAL SOURCE OF ZERO RADIANCE

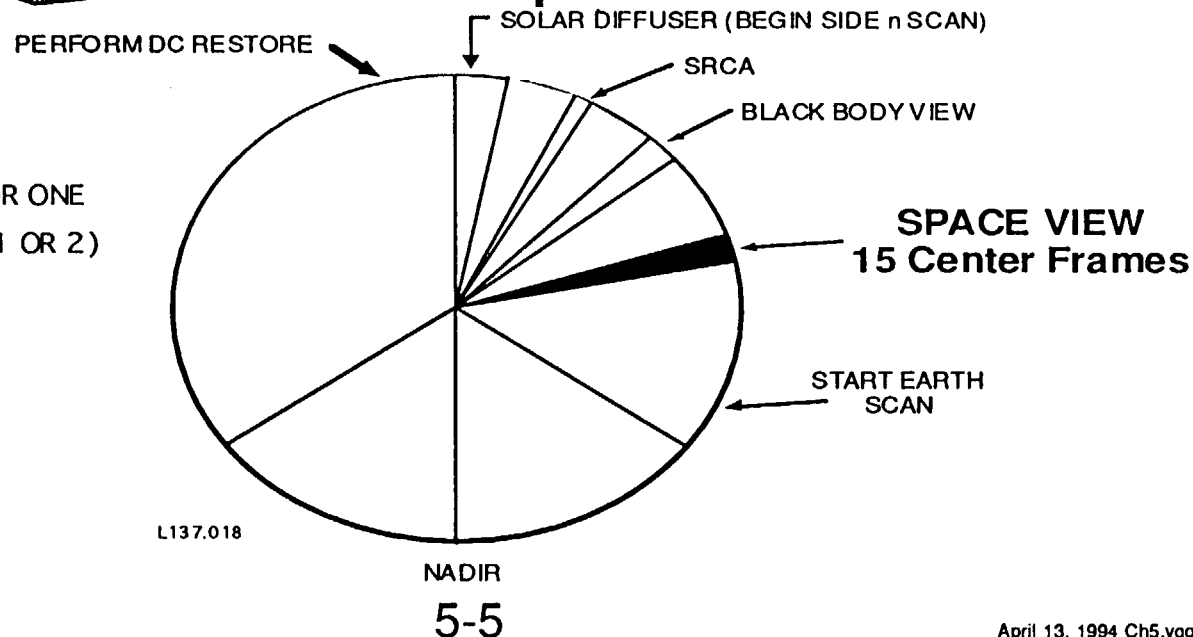


L137.017

APPROACH

- Determine if moon is in SV
- Take SV radiance to be zero
- Average over center frames
- Linearly interpolate SV counts to reduce 1/f noise
- **Result is first calibration point for all bands**

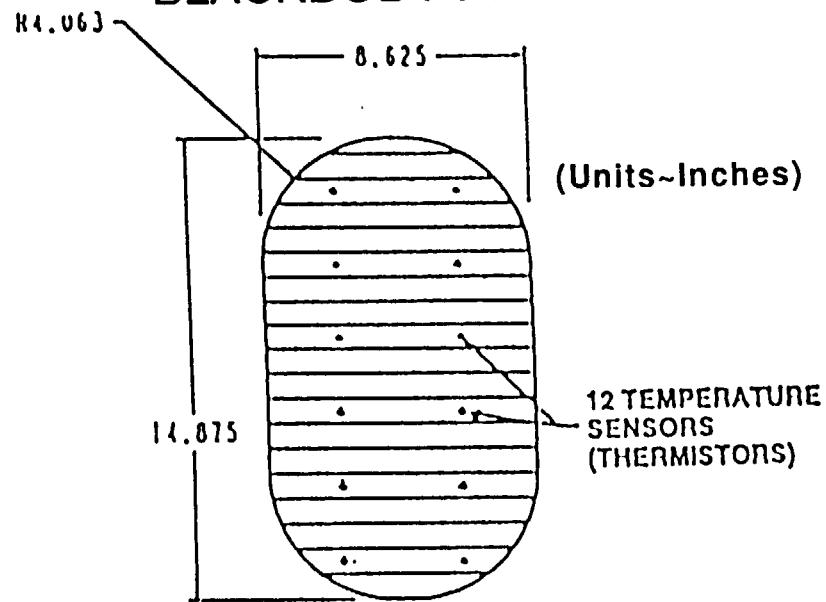
DATA SEQUENCE FOR ONE
SCAN (MIRROR SIDE 1 OR 2)



L137.018

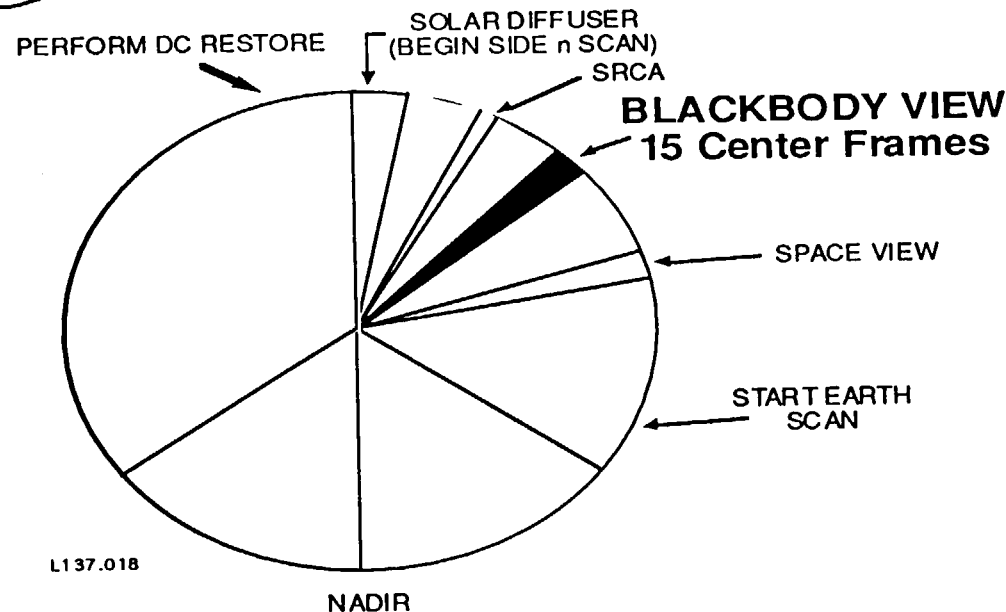
POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

BLACKBODY PROVIDES THERMAL CALIBRATION POINT



- APPROACH
- Ambient or heated mode
 - Use temperature sensors to calculate radiance
 - Average over center frames
- Result is second calibration point for thermal bands**

DATA SEQUENCE FOR ONE
SCAN (MIRROR SIDE 1 OR 2)



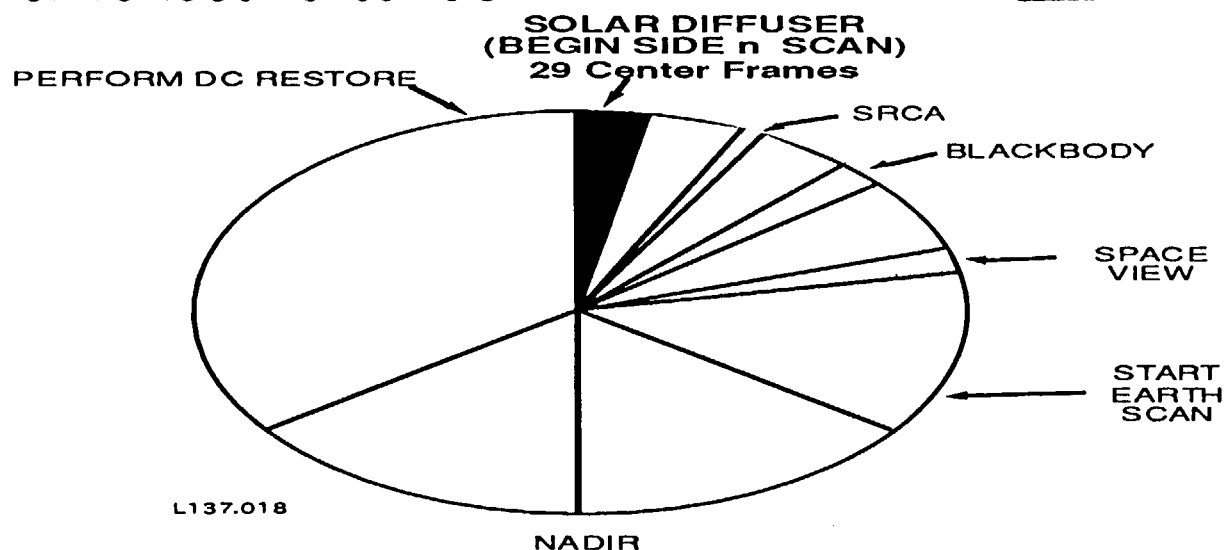
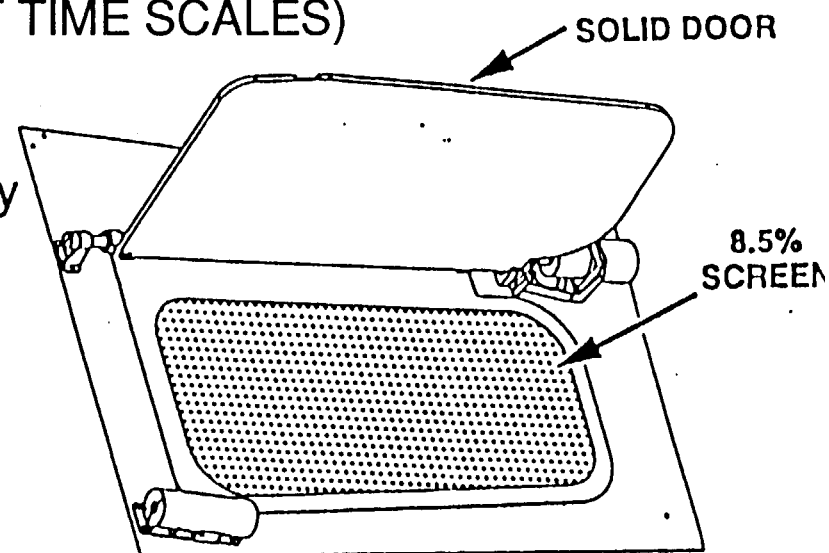
POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SOLAR DIFFUSER PROVIDES SECOND REFLECTIVE CALIBRATION POINT (INTER-ORBIT TIME SCALES)

APPROACH

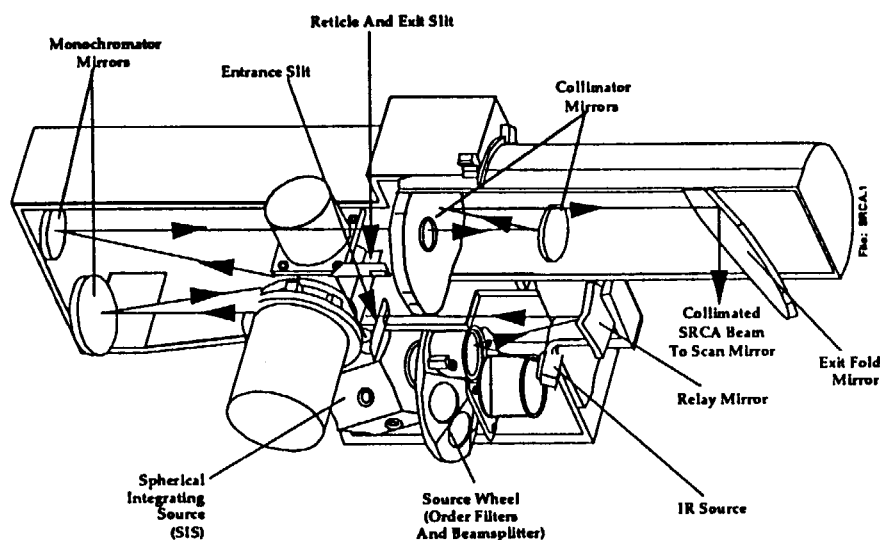
- Select SD reflectance level; full or screened
- Determine solar irradiance from orbital geometry
- Determine BRDF degradation from SDSM
- Calculate expected radiance
- Average over center frames

• **Result is second calibration point for reflective bands**



POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

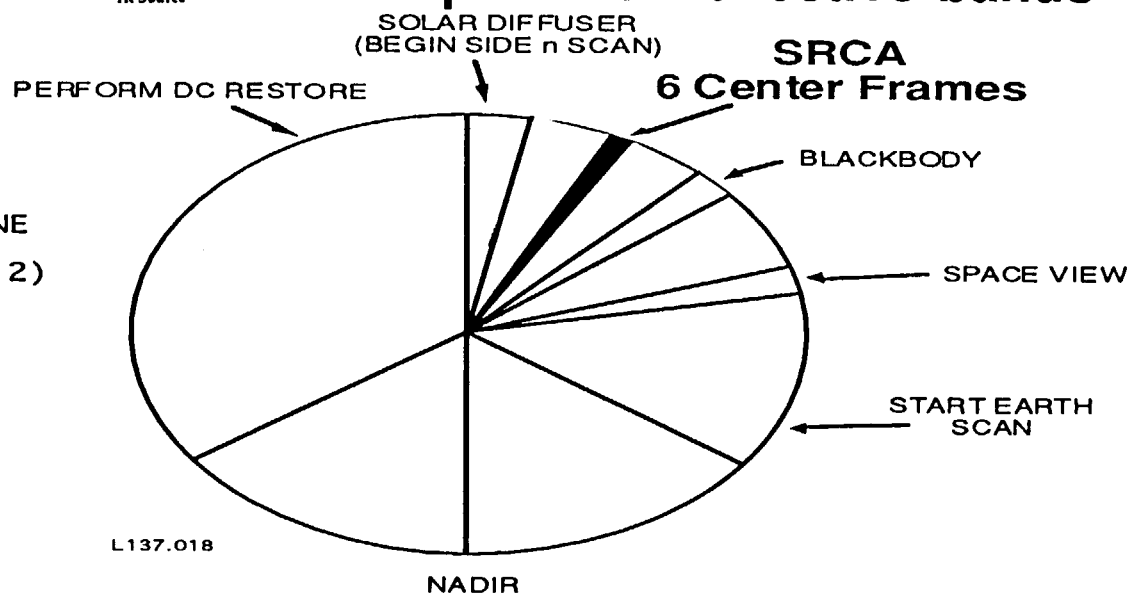
SRCA RADIOMETRIC MODE PROVIDES SECOND REFLECTIVE CALIBRATION POINT (INTRA-ORBIT TIME SCALES)



APPROACH

- Determine radiance level from lamps (6 available levels for optimum SNR)
- Account for partial aperture effects
- Average over center frames
- **Result is second calibration point for reflective bands**

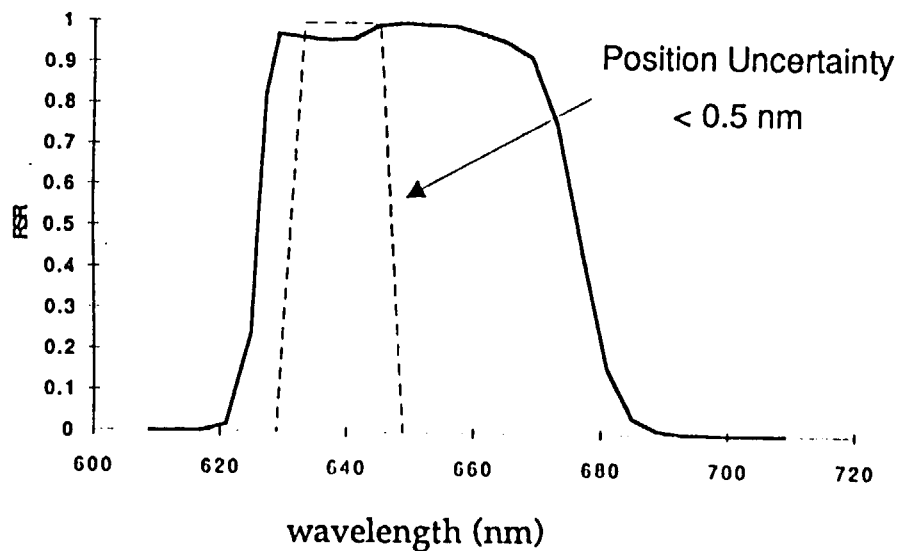
DATA SEQUENCE FOR ONE
SCAN (MIRROR SIDE 1 OR 2)



POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SRCA SPECTRAL MODE MEASURES CENTER WAVELENGTH SHIFTS FOR REFLECTIVE BANDS

Spectral Shape of Band 1 and SRCA Measurement



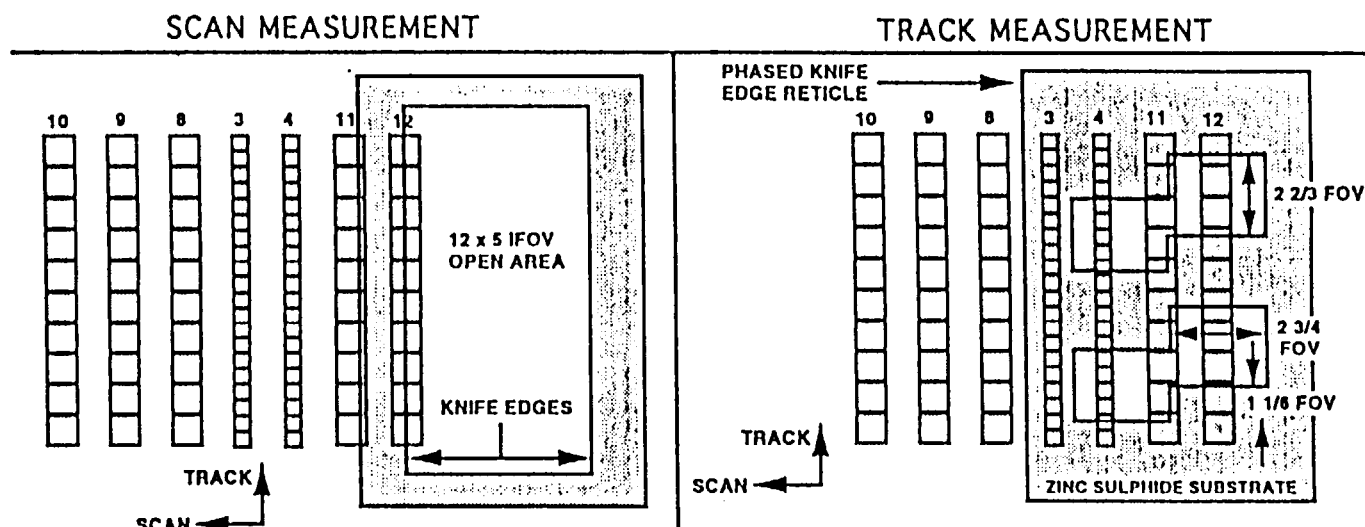
APPROACH

- ~20 data points/bandpass
- Set grating position to pre-launch calibrated position
- Self-Calibrate using the Didymium Glass/Diode
- Complex algorithm calculates center wavelength

SBRC is required to measure CW shifts to the specification uncertainties. MCST is studying methods to derive other spectral characteristics such as bandwidth from the SRCA data.

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SRCA SPATIAL MODE MEASURES BAND-TO-BAND REGISTRATION



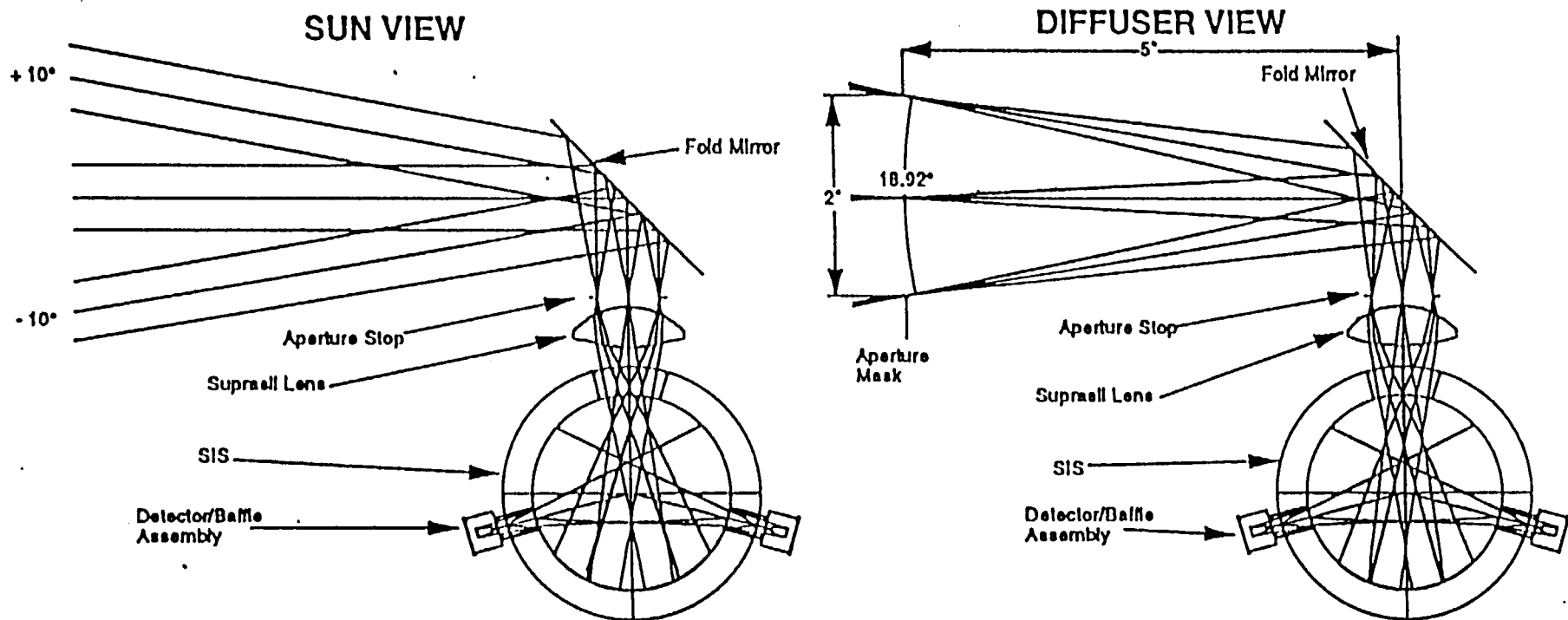
APPROACH

- Collect multiple scans
- Use phase delay settings to calculate centroid
- Determine Relative Registration

MTF determination may be possible

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SDSM PROVIDES MEASURE OF SOLAR DIFFUSER DEGRADATION

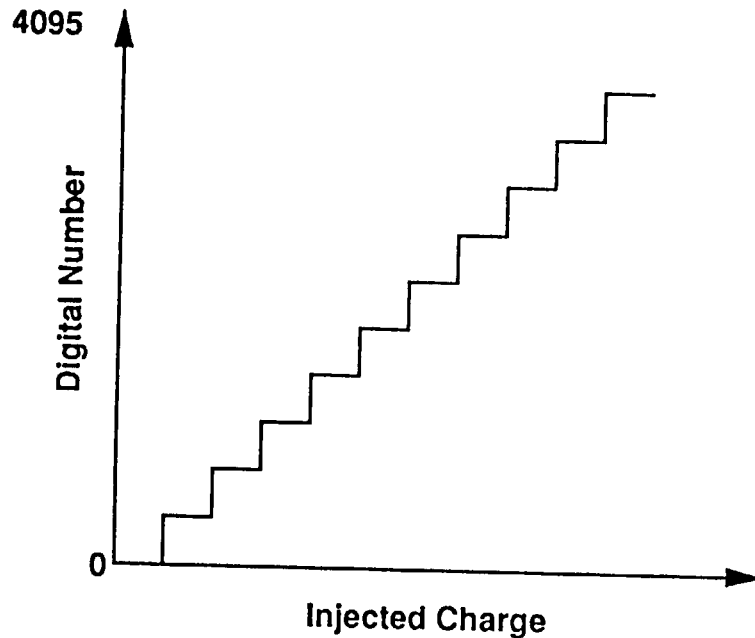


APPROACH

- Looks at SD and attenuated sun for >10 data sets/use
- Check directional reflectance at 11 wavelengths between 412nm and 1640 nm
- Average data
- Incorporate solar angles
- Calculate BRDF degradation constant

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

ELECTRONIC CALIBRATION CHECKS LINEARITY OF ELECTRONICS

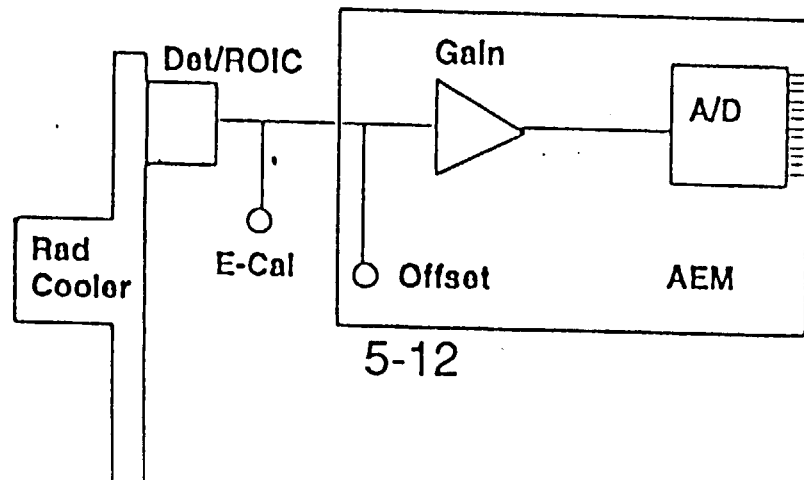


APPROACH

- PV detectors disconnected
- 25 points/scan bands 1-30 replacing SD data
- PC detectors cannot be disconnected
- 10 points/scan bands 31-36 on top of Space View
- Average over scans
- Compare to expected curve

May be possible to vary offset and get finer resolution at A/D converters (1 bit staircase). MCST is investigating.

Electronic Charge can be Injected Immediately Following the Detectors



POST-LAUNCH PHILOSOPHY FOR USING OBCs

The use of the on-board calibrators is to:

1. Transfer ground calibration/characterization to orbit during the Activation and Evaluation (A & E) phase.

The SRCA, BB, and possibly the SD/SDSM will transfer the radiometric calibration. The SRCA will allow changes in spectral or spatial response to be detected and characterized.

2. Verify instrument stability during A & E.

The OBCs will be used extensively during A & E to establish and characterize the stability or variability of the instrument. Additionally, the stability of the OBCs themselves will be determined.

3. Monitor the instrument during the Operational phase.

Having established the instrument stability and variability, the OBCs will provide regular calibration points and regular checks on the instrument characteristics (spectral, spatial, etc.).

4. Troubleshoot the instrument as necessary.

ALGORITHMS (1 of 2)

Development

- SBRC preliminary algorithms in CDRL 404, Operational In-Flight Calibration Procedures, January 1994.
- SBRC final algorithm delivery TBD.
- MCST at-launch algorithms completed January 1997.

ALGORITHMS (2 of 2)

Calibration Coefficients

1. Determine calibration points
(thermal: SV,BB; reflective SV, SD or SRCA)
2. Determine coefficients
3. Send to integration

Characterization Information

1. Convert to physical characteristic (i.e., CW, spatial shift, etc.)
2. Use in OBC algorithm as appropriate (i.e., SDSM)
3. Flag changes (to MCST/GSFC) for review
4. Send to Integration for inclusion in metadata

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

ERROR BUDGETS

CDR predicted uncertainties for on-board calibrators

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- Requirements from instrument specification
- Predicted Errors still evolving

BASIS FOR PREDICTIONS

- SBRC predictions based on budgets, experience, and available measurements
- MCST is reviewing these predictions
- Predicted uncertainties still evolving

VERIFICATION

Preflight verification of the OBC procedures and equations will be achieved in the thermal vacuum tests.

In-flight verification will be through comparisons with other calibration methods and with engineering telemetry.

PERSONNEL

- MCST will provide the primary personnel for defining the in-flight application of the OBC systems.
- The University of Wisconsin shall assist in planning the infrared calibration.
- Other organizations will be named as needed.

SCHEDULE

- Preliminary schedule determined.
- Lifetime and tradeoff considerations under study.
- Any changes to philosophy or assumptions will modify schedule.
- Final schedule to be determined during A & E.

Current Assumptions

1. Instrument will behave properly; safety margins not yet included.
2. It takes 30-100 samples to adequately characterize instrument stability.
3. Worst changes (spectral, spatial, etc.) will be at-launch--instrument will be stable (characterizable) after that.
4. Frequency of use is not a challenge to bulb or motor lifetimes.

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

CURRENT SCHEDULE

CALIBRATOR	Usage			
		DURATION	FREQ. A&E	FREQ. ON-ORBIT
SD/SDSM		1.5 - 3 min	240 Orbits	1/week
BB	Unheated	15 Data Frames	Every Scan	Every Scan
	Heated	TBD	TBD	TBD
SRCA	Full Radiometric	17 min	100 times	1/month
	10W bulb radiometric	full orbit	100 orbits	1/week
	1W bulb Radiometric	full orbit	100 orbits	1/week
	Full Spectral	75 min.	100 times	1/month
	Partial Spectral	TBD	as needed	as needed
	Full Spatial	37 min.	100 times	as needed
	Scan Direction Spatial	32 min.	as needed	4/year
Electronic Calibration	1W bulb Spatial	7 min.	TBD	TBD
		Regular Stairslep	TBD	1/week
SV		1 bit Stairslep	TBD	4/year
		15 Data Frames	Every Scan	Every Scan

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

MCST STUDYING LIMITATIONS TO USE

CALIBRATOR	LIMITATION	EFFECT ON USE
SD/SDSM	Door Motor Lifetime	Failure Mode Is Door Open/Screen Shut; Restricts Calibratable Bands; Speeds Degradation
	SDSM Motor Lifetime	Failure Kills Ability To Monitor SD
	SD Degradation	Large degradation may result in negligible SD signal
BB Unheated	None	
BB Heated	Thermal Gradients	Limits Usefulness during transitions, hurts DC restore
SRCA	Thermal Constraints	Limited to 2/8 orbits plus TBD
	Bulb Lifetimes	Limited bulb lifetime drives schedule; failure (past spares) restricts calibratable/characterizable bands;
	Motor Lifetimes	Failure mode is radiometric mode; lose spectral/spatial modes
Electronic Calibration Bands 1-30 Bands 31-36	SD Not in Use Uses SV	SD or EC but not both SV not available for radiometric calibration
SV	Moon in SV	Changes expected radiance

RISK ASSESSMENT

- Meeting the error budgets with the OBCs will be a challenge, especially over long time periods.
- There is some risk from future descopes to the SRCA.
- Once on-orbit, the Blackbody, Spaceview, and Electronic Calibration are expected to function for the entire mission. The SRCA, SDSM, and Solar Diffuser are given a 95% confidence by SBRC that they will last at least 6 months.

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

SUMMARY

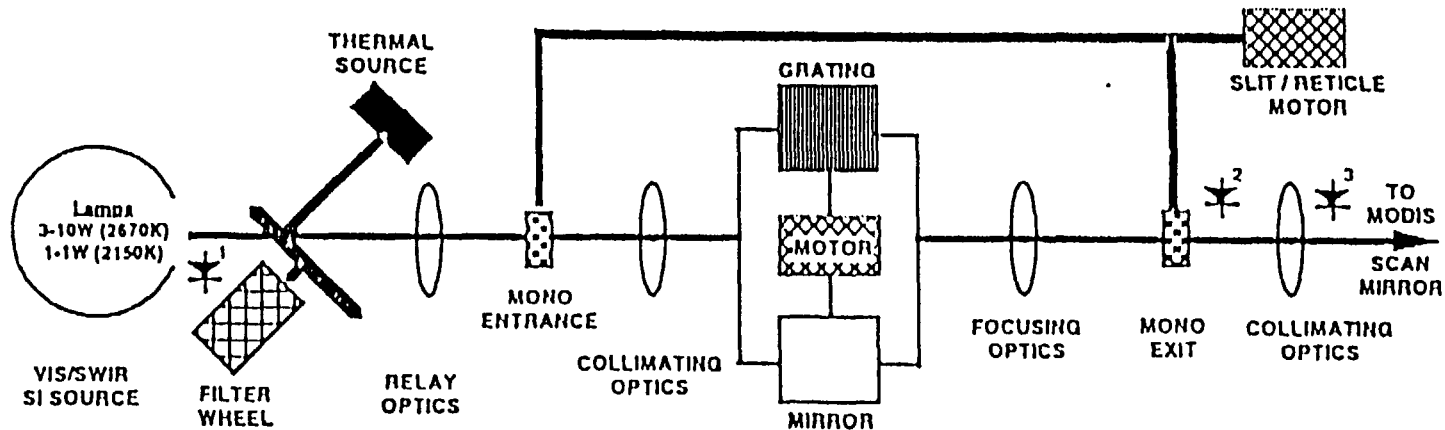
CHAPTER 5 SUPPLEMENTAL VIEWGRAPHS

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

TABLE 5.1 MODIS in-flight calibration summary (from SBRC CDRL 404, Dec. 1993)

Type of calibration	Source	Mechanism	Aperture	Spectral Bands	Usage Frequency (Max.)	Other Comments
Radiometric	Space		Full	MWIR / LWIR	Once per scan line	
DC Restore	Blackbody	Blackbody	Full	All	Once per scan line	
Radiometric	Blackbody	Blackbody	Full	Bands 20-25 & 27-36	Once per scan line	
Radiometric	Sun	Solar illuminated diffuser	Full	VIS / NIR / SWIR LESS BANDS 8-16	Once per orbit	Eff albedo 0.45-0.59
Radiometric	Sun	Solar illuminated diffuser	Full	VIS / NIR / SWIR	Once per orbit	Eff albedo 0.038-0.050
Diffuser stability monitor	Sun	Spherical integrator with filtered detectors	Full	VIS / NIR / SWIR	Available once per orbit	Both high and low albedo levels
Radiometric	Incandescent source with spectral shaping	SRCA collimator	Partial	VIS / NIR / SWIR	Available any time during orbit	
Spectral (MODIS)	Incandescent source	SRCA grating monochromator with collimator	Partial	VIS / NIR / SWIR	Available any time during orbit	Grating rotated
Spectral (Monochromator)	Incandescent source	Didymium filtered photodiode	Full	VIS / NIR / SWIR	Available any time during orbit	Grating rotated
Spatial Registration	Incandescent and IR sources	SRCA collimator with spatial reticles	Partial	All	Available any time during orbit	
Electronic Gain	voltage source		NA	All	Available any time during orbit	Injected at FPA

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS



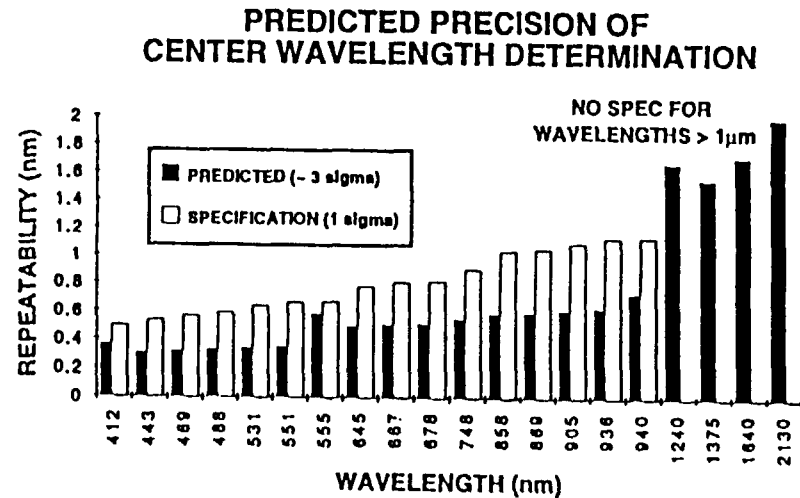
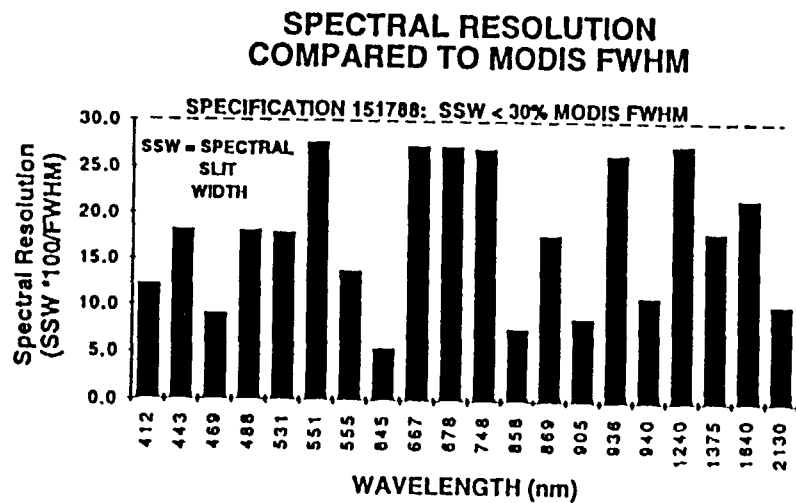
DETECTORS: 1 = SIS FEEDBACK CONTROL, 2 = DIDYMIUM SPECTRAL SELF CAL, 3 = SPECTRAL REFERENCE

CALIBRATION MODE	SOURCE	FILTER	MONO ENTRANCE	GRATING / MIRROR	MONO EXIT	ESTIMATED TIME REQD *
RADIOMETRIC	VIS/SWIR	CLEAR & NO ORDER (3)	OPEN	MIRROR	OPEN	20 min
SPECTRAL	VIS/SWIR	ITO DICHROIC	SLIT	GRATING	SLIT / SIPD ₃	70 min
SPATIAL	VIS/SWIR & THERM		OPEN	MIRROR	RETICLES	40 min

* DOES NOT INCLUDE TIME REQUIRED FOR TEMPERATURE STABILIZATION OF HEATED COMPONENTS: THERMAL SOURCE AND SIS FEEDBACK CONTROL DETECTOR

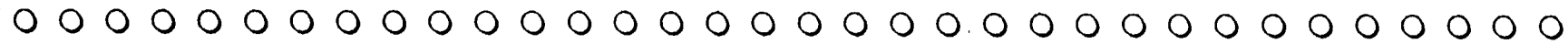
Schematic Representation of SRCA Calibration Functions

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS



POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS

Blackbody Parameter Summary



Material - anodized aluminum

Height - 14.875"

Width - 8.625"

Thickness - 1.091"

Weight - 8.3 lbs

Heaters - 2

Thermistors - 12 "bead in glass" thermistors

Blackbody "heat up" (285° - 315°) - 130 minutes

Blackbody "cool down" (315° - 285°) - 300 minutes

View Angle Range "clear view" - (230.750° - 232.050°)

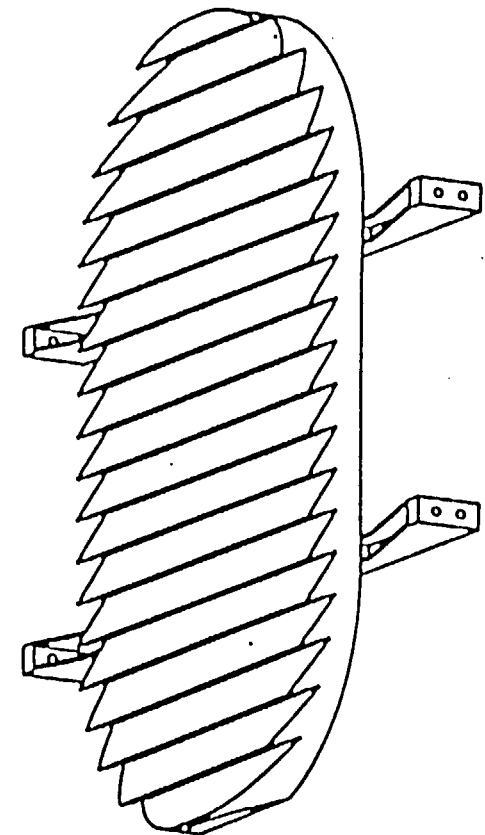
Number of "Clear View" Data Packets Per Scan - 15

Included Groove Angle - 40.5°

Index View Angle - 284°

Nominal Blackbody View angle - 231.4°

Angle of Incidence on Scan Mirror for Nominal View - 26.3°



V-GROOVE BLACKBODY

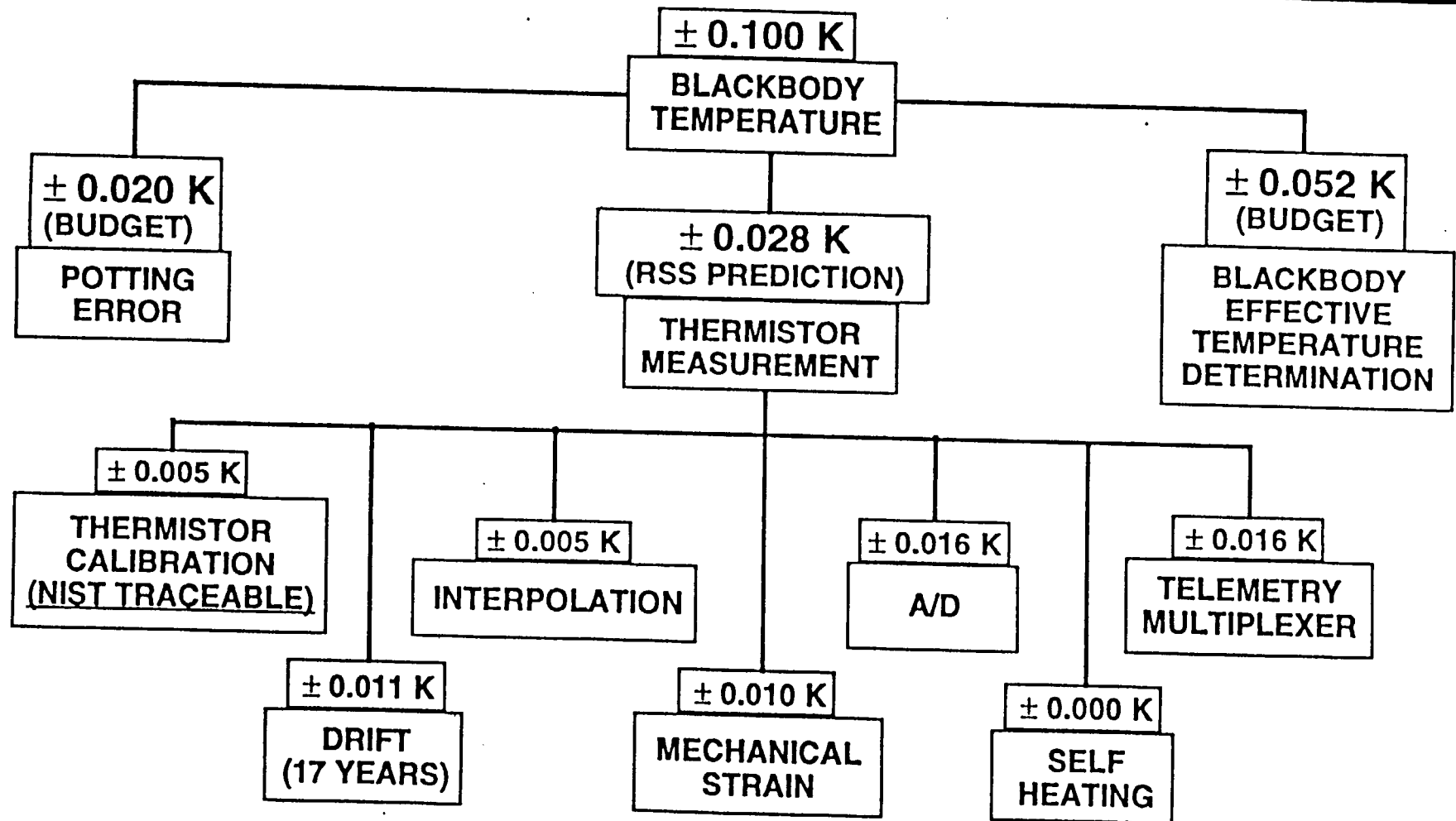
POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS



BLACKBODY TEMPERATURE ACCURACY MEETS ± 0.1 K REQUIREMENT

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POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS



OBC Blackbody Meets Thermal Performance Objectives

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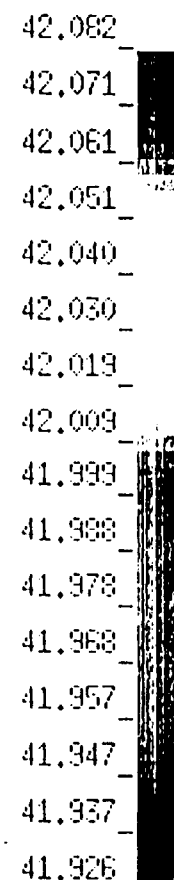
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- Requirement is 0.1°C average-temperature knowledge

- Budget flowdown allows 0.058°C for error between average surface temperature and average thermistor temperature.
- Current prediction is $<0.01^{\circ}\text{C}$ in both heated and ambient modes.

- Anodization offers advantages over paint

- Reduced surface gradients (0.15°C vs. 0.25°C)
- Coating thickness no longer thermally critical
- Performance in ambient and heated modes more similar
- Average thermistor-to-surface error reduced from 0.032°C to $<0.01^{\circ}\text{C}$



PDH/PATRICK POST-PRO
TIME=0.003
SURFACE 4 3
CALIBRATION PERFORMED BY SINPAT V3.0 31-DEC

OBC-Blackbody Surface Gradient Distribution ($^{\circ}\text{C}$)

POST-LAUNCH CALIBRATION USING ON-BOARD CALIBRATORS



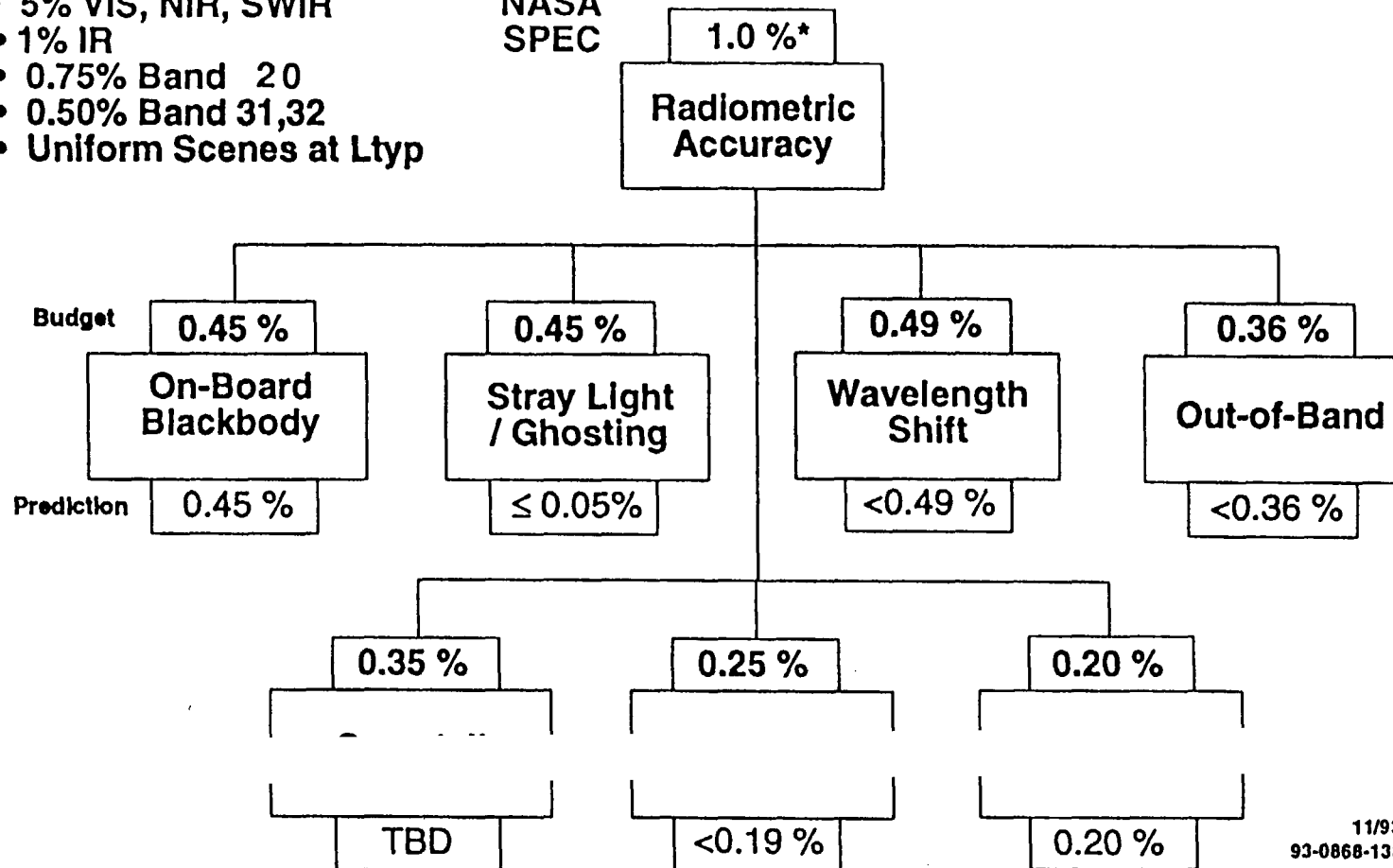
RADIOMETRIC ACCURACY BUDGET ESTABLISHED

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- * • 5% VIS, NIR, SWIR
- 1% IR
- 0.75% Band 20
- 0.50% Band 31,32
- Uniform Scenes at Ltyp

NASA
SPEC



11/93
93-0868-138

• SEE CDRL 101 FOR MODEL DESCRIPTION

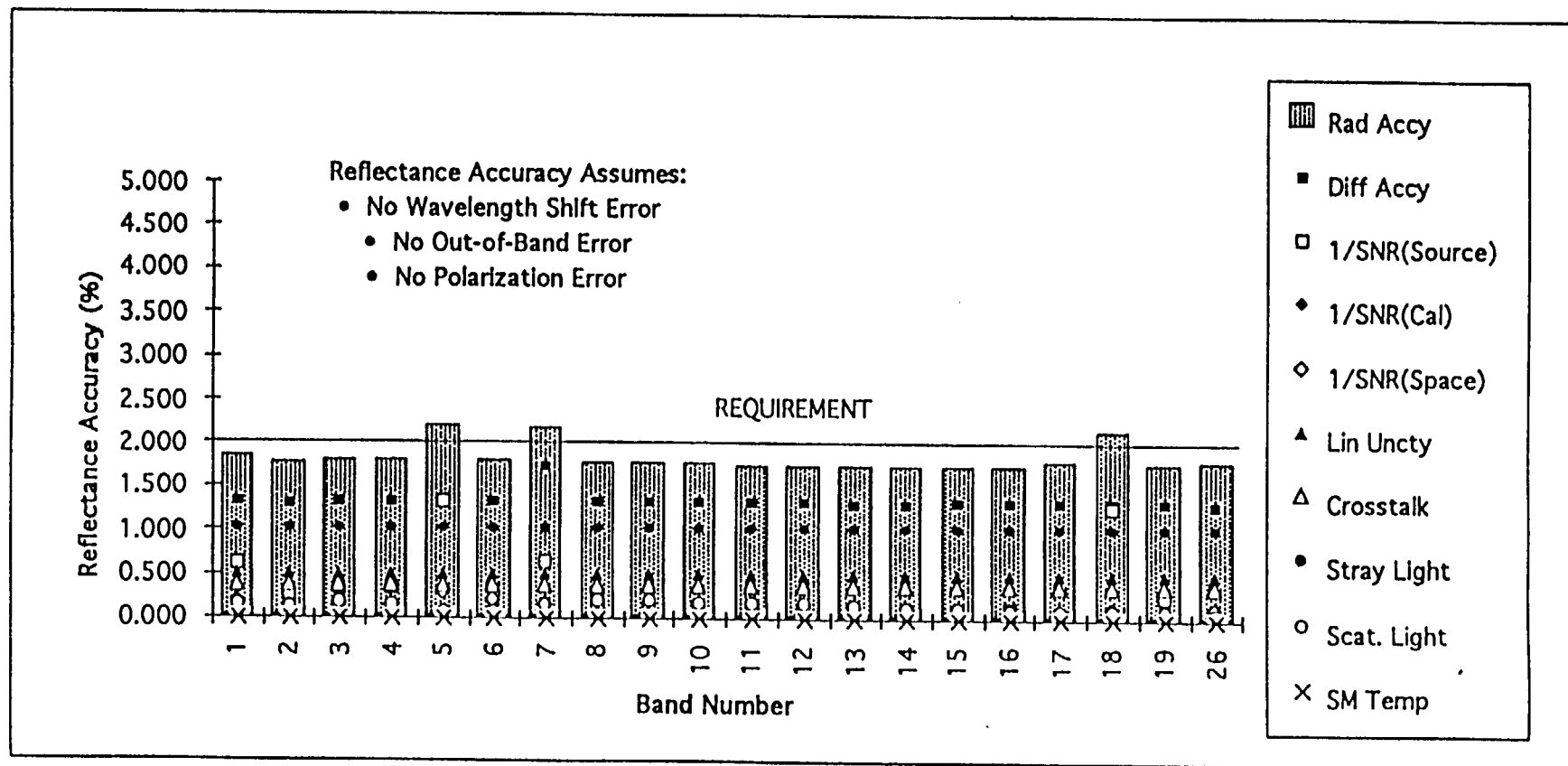
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REFLECTIVE BANDS MEET REFLECTANCE ACCURACY REQUIREMENTS

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- SINGLE SAMPLE SHOWN TO DEMONSTRATE HIGH PERFORMANCE
- BANDS 5,7, AND 18 MEET SPEC FOR MULTIPLE SAMPLES (SNR ERROR GOES TO ZERO)

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